International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 9, Issue 6, Dec 2019, 221–232

Original Article

PREDICTING HEATING TIME, THERMAL PUMP EFFICIENCY AND SOLAR HEAT SUPPLY SYSTEM OPERATION UNLOADING USING ARTIFICIAL NEURAL NETWORKS

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ABSTRACT

In the work herein has been carried out the performance prediction of the solar heat supply system with the thermal pump using artificial neural networks. Techniques of the artificial intellect (AI) become useful as an alternative approach to the conventional methods or as components of integrated systems for solving the complex practical problems in different fields and become more and more popular now-a-days. Experimental works on manufacturing the thermal pumps have been fulfilled for the depth of 0.5m, with performance parameters–heating time, pump efficiency and work discharge. By means of artificial neural network (ANN) the model has been developed for assessing the performance of the solar heat supply system with the thermal pump. The ANN model is quite well trained, it accelerates the training process, and further it has been said that the ANN is quite well trained for the solar heat supply systems.

KEYWORDS: Flat Solar Collector, Thermal Pump, Heat Supply Solar System & Artificial Neural Network

Received: Aug 05, 2019; **Accepted**: Aug 27, 2019; **Published**: Oct 17, 2019; **Paper Id**.: IJMPERDDEC201920

1. INTRODUCTION

In the work [1], they has been developed the solar thermal water pump efficiency and condensation time change, as well, the cycle time with the inclusion of a separate condenser and heating time, under different temperatures, also there has been computed the influence of condensation and heating time. Analytical evaluation of the solar thermal water pump systems performance is very complicated due to the participation of many parameters and typical non-linear and transient processes for them. Faster outcomes of ANN modeling simplify those situations [2]. In multidimensional information area the ANN can study the key information patterns. Kalogirou [3] has demonstrated the energy systems, using the ANN, having considered in details, how widely the method of predicting the performance of the energy systems using non-linear variables is used.

Bechtler et al. [4] have simulated the working characteristics of the liquid for the thermal pump vapor compression using the ANN. Mohanraj et al. [5, 6] have conducted the exergy analysis of direct expansion by means of thermal pump using the ANN, which gives very appropriate statistical indices, such as correlation coefficient. Deepali et al. [7] have computed the performance of the hybrid photovoltaic thermal double pass air collector under different weather conditions using ANN.

Prediction of the passive solar building energy consumption [8] and modeling the cascade refrigeration system [9] also has been done using the ANN with an appropriate accuracy. The given concise literature survey

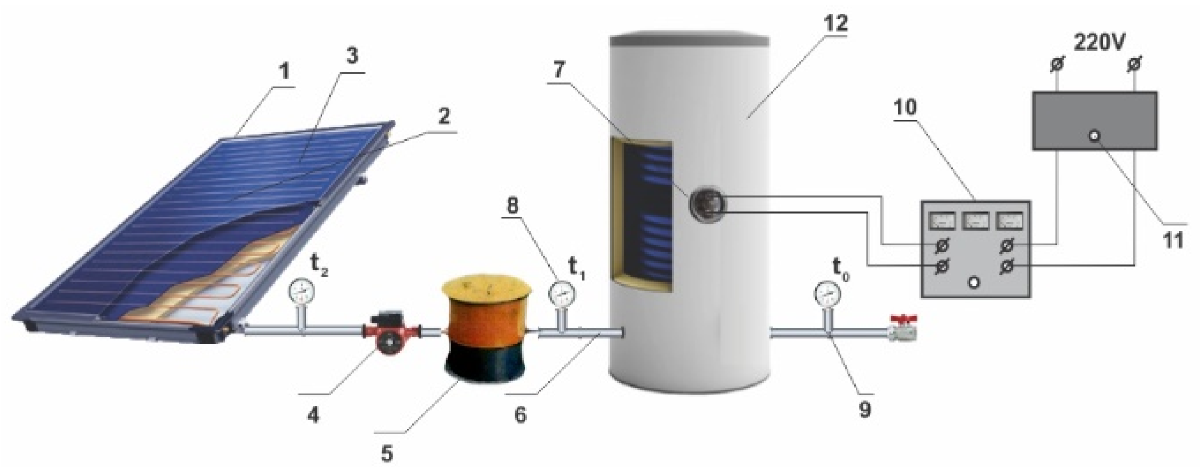
proves that many researches effectively used ANN for evaluating the productivity of the thermal and energetic systems. Studying of the ANN and fuzzy logic control (FLC) are two main branches of intellect control, the basis of which is the artificial intellect concept. Artificial intellect can be defined as a human being's thinking process computer emulation. Within the recent ten years there has been observed enough interest to the artificial neural networks. In particular, they are appropriate for the problems connected with incomplete data sets, fuzzy or incomplete information and highly complicated and poorly defined problems which the people usually solve intuitively [11,12,13].

The thermal pump has been developed and manufactured with a flat plate solar collector with 1 m^2. There has been made an attempt to assess the working capacity of the system under various working conditions with ANN modeling.

2. SOLAR HEAT SUPPLY SYSTEM

2.1. System Description

Figure 1 presents a principal diagram of the solar heat supply system. The diagram consists of heat insulated body 1, translucent cover 2, tank absorber 3, a circulating pump 4, a thermal pump 5, pipelines 6, thermal electric heaterwith a thermal regulator 7, thermometers 8, 9, for measuring the water temperature at the inlet (t1) and outlet (t2) from the tank and environment (tm), measuring deviceK 501 and auto transformer 11, as well, a controller for the management system. For the rational heat removal from the heat transmitting solar collectors and the solar system operation simplification, it is obviously profitable that the system there of operates with thermosyphon circulation. Therefore, to define the solar plant thermal modes, it is necessary to establish the dependence of production capacity on the solar radiation density standard characteristics, heat removal factor, ambient temperature, temperature difference, etc.



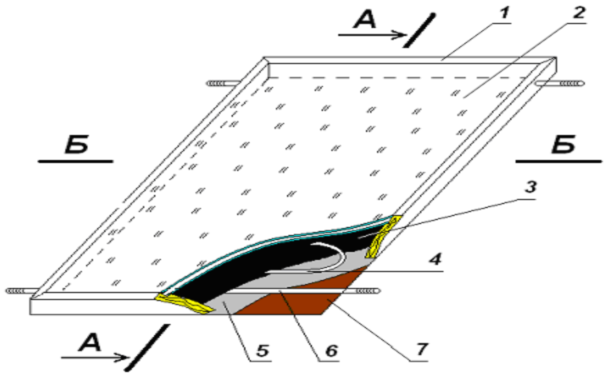
1 – heat insulated body; 2 – translucent cover; 3 – tank absorber; 4-circulating pump; 5 – thermal pump; 6 – pipeline; 7 – THE; 8, 9 – thermometers for temperature measuring at inlet and outlet from the tank-absorber and environment; 10 – kit of electric measuring devicesK 501; 11 – autotransformer; 12- tank-accumulator; 13-controller

Figure 1: Principal Diagram of Solar Heat Supply System.

Solar collector is the main heat generating unit of the solar plant on the energetic operational indices of which directly depend on the corresponding solar plant parameters. Therefore, the main mass of the inventions and patents, registered in the world are concentrated, mainly, in the area of creating the new structures and technologies for the solar collectors.

To achieve the set aim there have been developed principally new solar collectors on the basis of which there will be executed the solar plants standard series for water heating.

A standard example of such solar collector is a flat plate collector with a bitumen absorber (Figure 2).



Фиг. 1

Figure 2: Model of Solar Collector.

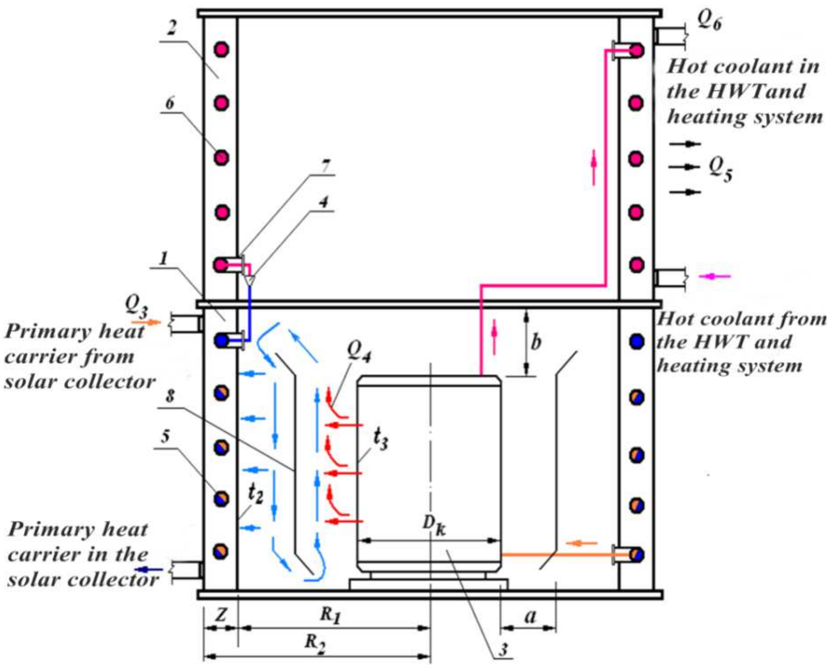
Figure 3: Solar Collector Mockup.

To achieve the desired goal, it is proposed to implement a new approach to design the solar collectors using modern materials and at that expense to gain a sufficient reducing (2–3 times) in the solar plant cost. Concept and novelty of the offered method are in its distinction from the known design principle, the collector thereof contains a transparent glazing 2 with double glass with lower pressure, as well a perimetric frame 1. Wooden frame bottom 7 is made of 8 mm thickness plywood with an attached heat insulated film 5 with foil. In the gap between the glazing and frame bottom there is laid a flexible stainless corrugated pipe 4 ∅ 16 mm in the coil form. Tubes edges are fixed to the input and output protruding tubes 6. The remaining space is filled with bitumen 3 of 30 mm thickness grade.

Table 1: Technical Specification of Flat Plate Solar Collector

Number of Transparent Insulation Layers	**2**
One collector square, m^2	up to 2
Water heating average temperature, $^{\circ}C$	60–80
Carrying capacity in respect to the solar radiation upon the sun rays falling normally on the surface	0,89
Specific volume for transfer media, l/m^2	2,0
Absorbing capacity as regard to solar irradiation	0,99
Working pressure, MPa	0,7
Overall dimensions, m	1x2
Product of the optical factor and absorbing panel efficiency coefficient	0,8
Product of general collector's thermal losses factor and absorbing panel efficiency coefficient	0,75
Ratio of the heat absorbing surface square to the overall square	0,95
Collector's mass, kg	60
Life cycle, years	15

The main element of the studied circuit is the thermal pump. Figure 2 gives the diagram of the new technical solution for the thermal pump in section. The proposed device allows to utilize the heat released by a compressor in the operation process and simultaneously cool it.



1 – evaporator heat exchanger; 2 – condenser heat exchanger; 3 - compressor; 4 – throttling valves 5 and 6 – pipes for evaporator and condenser cooling medium; 7- hole for pipes entry into condenser's body; 8 – grilled barrel-divider of air flows.

Figure 4: Design Diagram of the Thermal Pump New Technical Solution for Solar Plant and Main Structural Parameters.

Table 2: Main Thermal Pump Structural Parameters Coolant.

Outer Diameters of Evaporator and Condenser (D_2), mm	375,0
Inner diameter (D_1), mm	325 and 307
Height of heat exchanger jackets, mm	355 and 382
Heat exchangers jackets width (Z), mm	20 and 30
Heat exchangers jackets volumes, dm^3	0.52 and 0,8
Core barrel-divider diameter, mm	238
Excess of evaporator height over compressor height, mm	80,0

Heat exchangers of evaporator 1and condenser 2 are made in ring-type form vessels, formed with inner and outer cylindrical barrels with radii $R_1$and R_2 and are installed one over the other coaxially, underneath-evaporator, above-condenser, forming internal cylindrical air chamber. In the evaporator heat exchanger chamber, there is installed a compressor 3. To secure optimal heat exchange from a compressor to an evaporator in the gap between them there is placed a cylindrical grilled barrel-divider 8. Inside the ring-type vessels there circulated the transfer media of the1st and 2nd circuits removing the heat from pipes 5 and 6. Thus, a compressor practically is inside «a cold pot», the walls of which are cooled with the tubes cooling media 5. Consequently, the heat released with a compressor is absorbed with a thermal pump evaporator upgrading its productivity, and a compressor is simultaneously cooled without a ventilator usage.

Figure 5: Thermal Pump.

Analysis has shown that the thermal pump's new solution for the solar heat supply system without accounting the energy expenditures on the refrigerating ventilator drive promotes the heat productivity raise.

2.2. Uncertainty Analysis

Uncertainty determination in the measurements during the experiment is an important moment. The only measurement, necessary for defining the thermal pump productivity is the solar irradiation, pressure and water amount. The mistake connected with pyranometer which is used to measure the solar radiation constitutes ± 5%.

Uncertainty propagation method [14] might be used for specifying the combined effect of measurement accidental errors. According to the method thereof a result R represents a prescribed function of the variables $x_1, x_2, x_3, x_4, \ldots x_n$. Thus,

$$R = R(x_1, x_2, x_3, x_4, \ldots x_n) \quad (1)$$

Let W_R be uncertainty in the result, and w_1, w_2, w_3, w_4, w_n are uncertainties in the independent variables.

3. DEVELOPMENT OF ARTIFICIAL NEURAL NETWORK

An appropriate instrument for predicting, functional approximating, optimizing, modeling and predicting thermal system's productivity, as well computing the processing high speeds makes use of the artificial neural networks [2, 16]. Artificial neural networks, consisting of simple elements operate in parallel. They study the relations between input parameters and controlled and uncontrolled variables having been recorded previously. One more advantage of artificial neural network usage is its ability to process the big and complex systems with many interrelating parameters. The network usually consists of an inlet layer, several hidden layers and an outlet layer. The neuron quantity in the input layer equals to the input parameters amount, and neuron quantity in the output layer equals to the output parameters amount.

ANN modeling is fulfilled in two stages; the first step is the network training and the second step is checking the network with the data, which is not used for training. Though the training consumes much time, the ANN promptly takes operation decisions. ANN is trained with an appropriate training method for fulfilling the certain function,

regulating the weight value. The training process continued while the network output coincides with the desired output. Weights changes and shifts reduce the mistake between the network output and desired output. Training process completes when a mistake falls below the certain value. The network uses the training mode in which the inputs are presented in the network together with a desired result and the weights are corrected in such a manner, in which the network tries to produce a desired result.

The network's architecture, selected by means of input and output parameters is shown on figure 4. The input parameters for the present work are the solar radiation, obtained per square unit, thermal pump charger and ambient temperature. The solar emission is the energy of the solar radiation, falling on the flat solar collector for appropriate water heating time in the definite operation cycle. The second input parameter is the thermal pump charger and the present work is executed for 0.5m depth. The third input parameter, an ambient temperature is also recorded for each heating time magnitude. Output parameters in this work are heating time for operation's every cycle, thermal pump performance and expenditure from the system.

Performance is the ratio of hydraulic works, executed for a definite delivery head in the charge cycle to the solar energy input to the cycle thereof. Mathematically the system's efficiency might be written as follows:

$$\eta = \frac{\rho_w * V_w * g * H}{I_\beta} \quad (2)$$

where H –delivery head in m, V_w–uplifted water volume and I_β- solar irradiation intensity in Wt. / m^2.

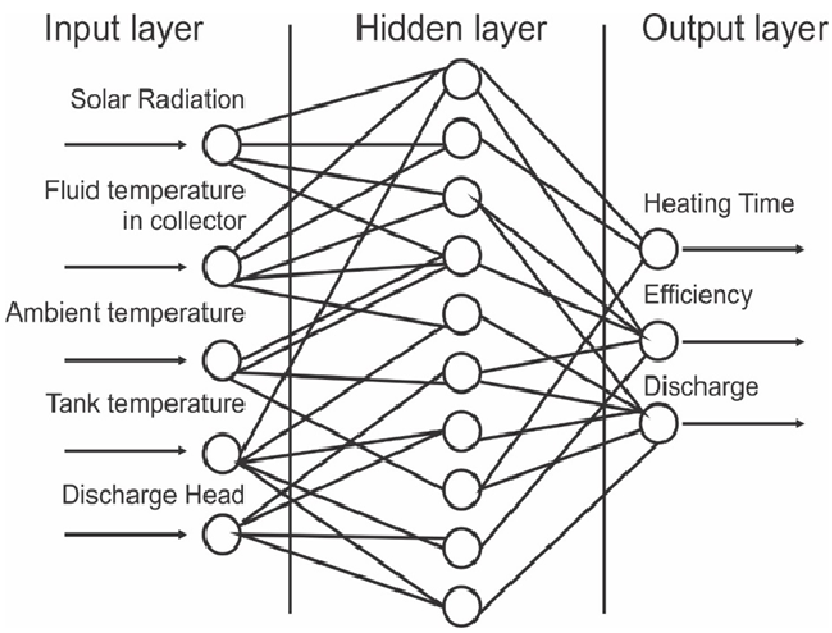


Figure 6: Network Architecture for Flat Plate Solar Collector with Thermal Pump.

Obtained experimental data is used for the network training.

Hereby 100 data sets are used for the network training. Input data is divided into training sets (70%), checking sets (15%) and sets for testing (15%). In the modeling herein, there has been used a training algorithm with one hidden layer. Omitting the mistake propagation from the output layers to the lower layer, the algorithm optimizes synaptic weight (hidden layer and input layer). In each step the computation mistakes are compared to the desired result. The model ANN approximates the desired result from each iteration to reduce mistakes and the mistakes further are transferred to the ANN

for the weights regulation. The network is trained until reaching the selected mistake goal. In the work herein, there is used a sigmoid transmission function Tan as an activation function for the hidden and output layers.

General form of the sigmoid function Tan [15]:

$$\sigma(t) = \frac{e^{t}-e^{-t}}{e^{t}+e^{-t}} \quad (3)$$

where t –weighted sum of input data.

For easy convergence, the training and testing information values are normalized within the range of 0–1. To use the training function, there has been selected Levenberg–Markvardt function with an input layer, consisting of three neurons and an output layer having three neurons. Neurons quantity in the hidden layer is selected based on the correlation coefficient. From the Table 1, it is clear that, when the neurons quantity in the hidden layer equals to 10, the correlation coefficient has the most value.

ANN model productivity is assessed in view of three statistical parameters: correlation coefficient (CC), average percentage of error (APE) and root-mean-square error (RMSE). They are computed according to the following equations [17].

Table 3: Correlation Coefficient for Various Neurons Quantity

No. of Neurons in Hidden Layer	Correlation Coefficient
7	0,99988
9	0,99978
12	0,99965
14	0,99897
16	0,9984

$$RMSE = \sqrt{\frac{(X_i-Y_i)^2}{N}} \quad (4)$$

$$CC = \frac{N\sum(X_i*Y_i)-\sum X_i \sum Y_i}{\sqrt{(N\sum X_i^2-(\sum X_i^2)(N\sum Y_i^2-(\sum Y_i^2))}} \quad (5)$$

$$APE = \frac{1}{N}\sum(\frac{abc(X_i-Y_i)}{X_i}) * 100 \quad (6)$$

where X_i -experimental values and Yi - ANN predicting output values.

4. OUTCOMES AND DISCUSSIONS

In the research herein, the experiments with a thermal pump have been carried out at 0.5 m depth. Experimental works have been conducted continuously for one week. A flat plate solar collector has been exposed to radiation every day starting from 7 am and a thermal pump has been ready to fulfill its first cycle by 11 am.

Figure 7 shows the solar radiation change during a sunny day in time. In summer time the solar radiation is much less in the morning and gradually increases by the mid-day and further decreases, it is the standard change tendency. Maximum solar radiation solubility per day with experimental data has been between 11 am and 5 pm.

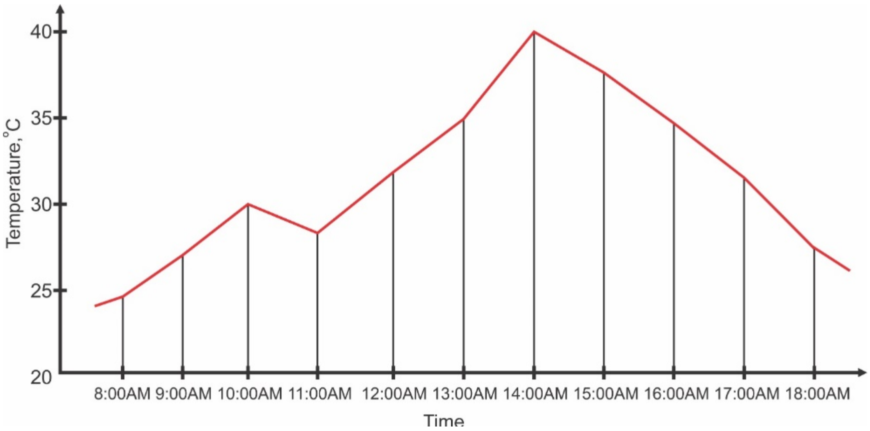


Figure 7: Solar Radiation Change in Time in Sunny Day.

Thermal pump shows better productivity within that time interval and experimental results exactly coincide. Heating time at mid-day turns out to be much less comparing to another time.

Figure 8 demonstrates the ambient temperature change in time. Diagram shows as well the solar radiation curve data, the solar radiation directly influences the ambient temperature.

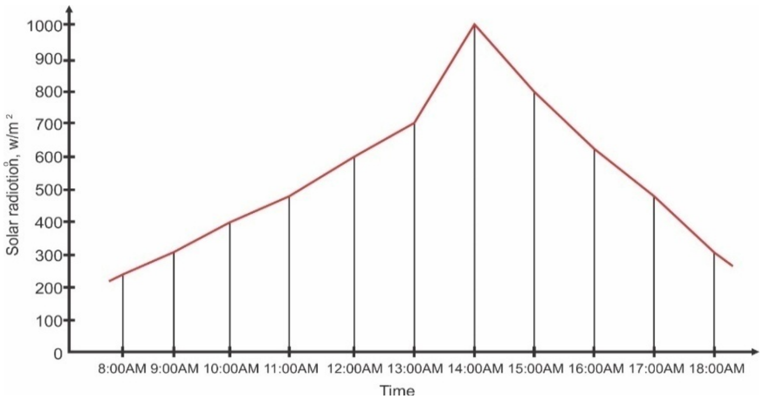


Figure 8: Ambient Temperature Change in Time.

Figure 9 presents exact pressure change, when a thermal pump is in operation at 0.5m depth, which fluctuates between two limits.

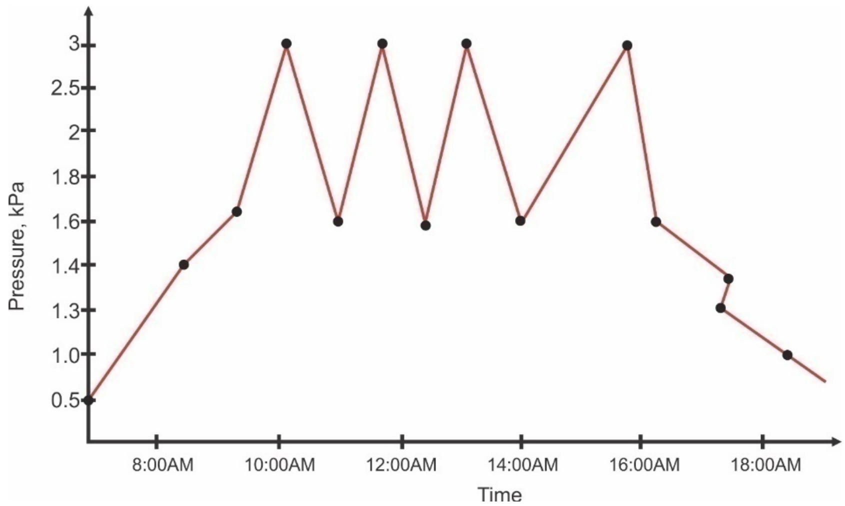


Figure 9: Exact Pressure Changes in Time.

Table 4: Cycles Quantity Per Day, Expenditure and Efficiency

S. No.	Delivery Head (m)	No. of cycles Per day	Discharge (liters/day)	Efficiency
1	0,5	6	30	0.16

Table 4 shows the cycles amount, expenditure and efficiency of the thermal pump per day. Proceeding from experimental works there has been stated the maximum cycles amount, that the thermal pump executed for delivery head. Performance depends on cycles quantity per day and labor capacity. Efficiency raise is conditioned with labor capacity per a cycle, in which there prevails an effect of performance decrease due to reducing the cycles amount per day at bigger heights, the efficiency upgrades along with the height increase.

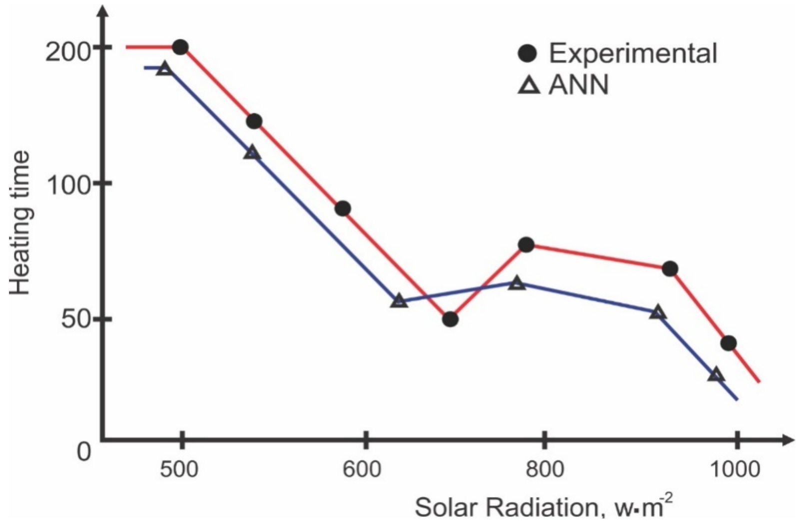


Figure 10: Dependence of Thermal Pump Heating Time on Solar Radiation.

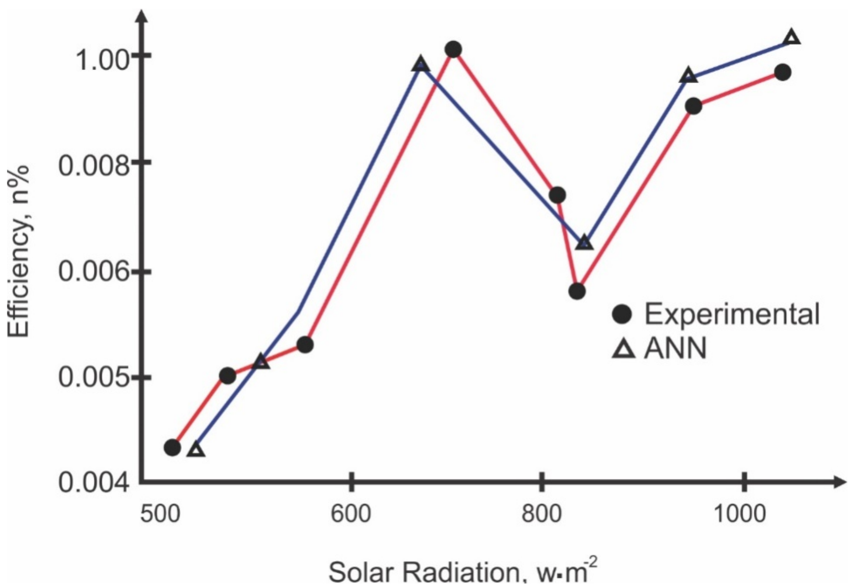


Figure 11: Dependence of Thermal Pump Performance on Solar Radiation.

Proceeding from the performance analysis, it is seen that along with the heating time increase the pressure on delivery head increases more. As the performance parameters as efficiency and water flow, dependent on the heating season, they decrease along with the height increase.

Decrease of cycles quantity takes place, when the water head increases the pressure, required for head delivery.

From the test data, the heating time, heat pump efficiency and discharge are simulated for a depth of 0.5 m using a model developed by ANN. The experimental results are compared with ANN forecasts for heating time, cycle efficiency and unloading of the heat pump at a depth of 0.5m figure 8. The results confirm that the predicted ANN values are in good agreement with the experimental values.

ANN model productivity is assessed from the view of three parameters: correlation coefficient (CC), average percentage error (APE) and mean square error (MSE). Comparison of ANN predictions and designed values of the heating time, cycle efficiency and expenditure give the correlation coefficients 0.99326, 0.99548 and 0.99430, accordingly. Values RMS and APE for the heating time, cycle performance and expenditure are given in the table 5.

Table 5: Capacity Parameters for ANN Model

Parameters	Heating Time	Efficiency	Discharge
RMSE	0.000128	0.000089	0.000456
CC	0.99458	0.99654	0.99457
APE	2.95	2.87	3.98

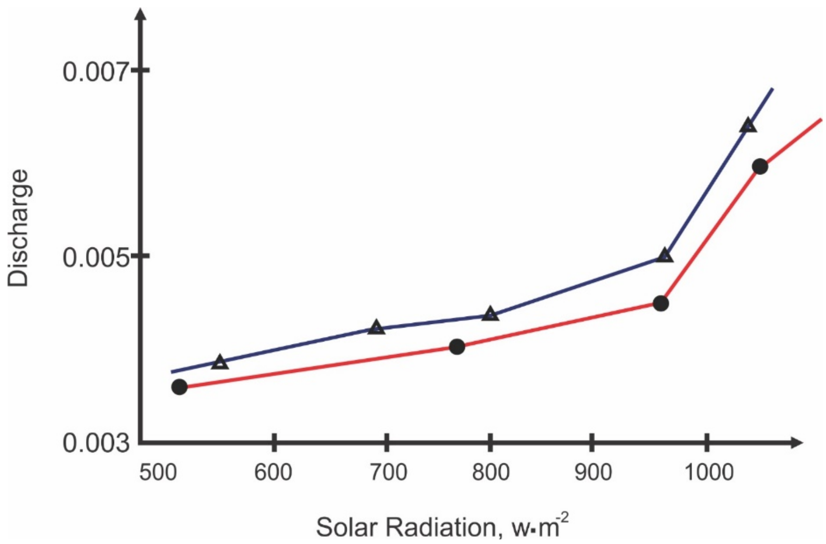


Figure 12: Thermal Pump Discharge Dependence on Solar Radiation.

5. CONCLUSIONS

The work herein has assessed the experimental works on manufacturing the thermal pump, operating at 0.5m depth with parameters of productivity: heating time, pump performance and discharge. The thermal pump is able to fulfill 7 cycles per day. An effective flat solar collector has improved the heating time for the liquid work and vapor condensation, which turns out to be a crucial time factor, necessary for completing any working cycle. During the experiment there has been observed the high heating time for each working cycle at any height. Under different working conditions there has been elaborated the artificial neural network model for assessing the capacity of the solar heat supply system with a thermal

pump. ANN system model has predicted the outcomes and designed values of the heating time, efficiency and correlation coefficient discharge.

This work is supported by grant from the Ministry of Education and Science of the Republic of Kazakhstan within the framework of the Project «BR05236693 "Mathematical and computer models, hardware and software tools and experimental development on creation of network combined effective dual-circuit solar collectors with thermo siphon circulation and monitoring of their functioning».

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